

# Fatigue Analysis of Large-deformation Cutting Tool Used in Cutting-off Sugarcane-leaf Returning Machine

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## Abstract

The cutting tool of cutting-off sugarcane-leaf returning machine was nonmetal material and rotated at high speed during working in field. The flexible cutting tool had large deformation when it stroked the ground. According to the working condition of the cutter, the study researched the fatigue properties of the nonmetal cutting tool. In order to obtain the fatigue load spectrum of the stress, the ground stroking process of the rotary cutting tool was analyzed by Finite Element Method (FEM) software ANSYS/LS-DYNA according to the operating feature of the rotary cutting tool. Loading the fatigue load spectrum from ANSYS/LS-DYNA, Virtual Proving Ground (VPG) software calculated the fatigue life of the cutting tool. The result of stress and fatigue indicated that the fatigue critical site was caused by the large deformations and the frequent deformations. The fatigue life of cutting tool satisfied the duration of the machine at the working speed (3000r/min) by simulation. The fatigue simulation of the cutting tool reduced the testing time and cost. Researching fatigue properties of the nonmetal cutting tool could provide an effective method to analyze the fatigue life of large-deformation nonmetal.

## Keywords

*Sugarcane Leaf; Returning Machine; Large Deformation; Fatigue Property; Finite Element Method*

## Introduction

In China, more and more scholars thought highly of sugarcane leaf returning back to the sugarcane field (Li Ming, 2008; Sopa Cansee, 2011). So in this sphere, the scholars acquired a lot of research production. Thereinto, the cutting-off sugarcane-leaf returning machine with flexible cutting tool not only finished the sugarcane leaves returning, but also protected the ratoon, which was the newest research object in sugarcane-leaf returning researches.

The cutting tool is a flexible body. And soil is a complex mechanical body. Both of them have

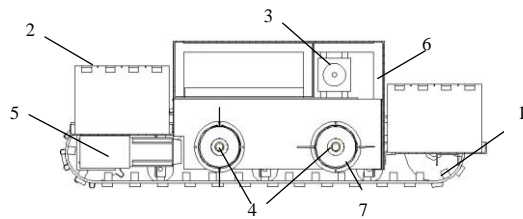
nonlinear material characterisation and stress regulation. The ground stroking process of the rotary cutting tool was analysed by the FEM software ANSYS/LS-DYNA (Xia Junfang, 2013). The fatigue analysis of flexible cutting tool was different from the fatigue analysis of metal structure. The material of tool is PA66 which is elastomer, but its young's modulus is lower than metal. The fatigue research of nonmetal began relatively late (Walter Schütz, 1996; M.L.Williams, 1980). Its study is only used at the application level without any general formal(10-12).

Because ANSYS software was unable to solve the problem of nonlinear fatigue assessment, the Virtual Proving Ground (VPG) software was used. It was able to calculate the finite element method simulation of nonlinear problem (Cui Can, 2012). Loading the fatigue load spectrum from ANSYS/LS-DYNA, Virtual Proving Ground (VPG) software calculated the fatigue life of the cutting tool. In the view of practical application, this paper tried to analyse the fatigue characterization of flexible nonmetal from a new perspective.

## The Working Mechanism of Cutting-off Sugarcane-leaf Returning Machine

The structure of cutting-off sugarcane-leaf returning machine was shown in Figure 1. The machine used the crawlers to walk and pressure the sugarcane leaves. Between two crawlers, it equipped two rotary cutterhead roller, and the cutting tool was installed in the cutterhead (Jing Wang, 2014). The machine could cut off the sugarcane leaves efficiently at the working velocity (3000r/min). When it completed sugarcane-leaf returning, it would not destroy the ratoon. Made of the nonmetal tool, its volume and weight were smaller than the traditional one. However, flexible tool was easy to get damaged, and the user had to replace

the broken tool in time. For this reason, this paper should assess the fatigue life of the cutting tool.



1.crawlers 2.battery 3.working motor 4.rollers 5. driving motor 6. frame 7. cutterheads and cutting tool

FIG. 1 RETURNING MACHINE

### The working Process Simulation of Cutting-off Sugarcane-leaf Returning Machine

The simulation of returning machine had two pieces of assumption. Firstly, supposing that the model of simulation the cutting tool rotated at the same velocity(3000r/min) in the same environment. So the simulation analysed a cutterhead. Secondly, the deformation caused by air and sugarcane leaves was tiny. So the model ignored the influence of the air and sugarcane leaves.

#### Modeling of Cutterhead and Cutting Tool

The diameter of the cutterhead was 110 millimeter, and the radius of minimum fillet was 0.5 millimeter. If the original model was meshed, the number of mesh was enormous. So the model should be simplified. Firstly, the texture of cutterhead could be simplified, because cutterhead which had longer fatigue life was not the major research object. Secondly, the part of cutting tool which didn't whip the ground was ignored. The original model and simplified model were showed in Fig.2. The positional relation and contacting relation between cutterhead and cutting tool in the simplified model were the same as ones in the original model. After simplification, the operation didn't have the negative volume, and the operation time was one tenth of the original one. The discrepancy of the operation figure between two models was less than 0.1 percentage.

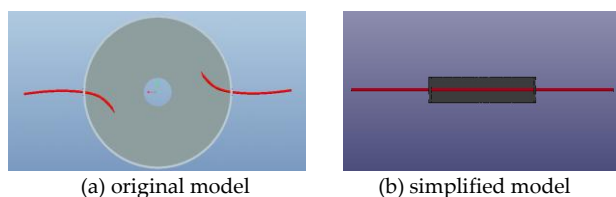


FIG.2 CUTTERHEAD AND CUTTING TOOL MODEL

The element style of cutterhead and cutting tool was SOLID164. The material model of cutterhead was

MAT\_RIGID, and the cutting tool was MAT\_ELASTIC. The material parameters of two material models were showed in TABLE 1.

TABLE 1 MATERIAL PARAMETERS

Model	Density $\text{kg}\cdot\text{m}^{-3}$	Poisson's ratio	Elastic modulus MPa
Cutterhead	9850	0.3	210000
Cutting Tool	1140	0.3	3100

#### The Simulation Model of the Ground

The main kinds of plant soil in sugarcane planting were clay loam, red loam and sandy loam. In Guangdong, sugarcane area was red loam, as TABLE 2 shown. The element style was SOLID164, and the material model was MAT\_FHWA\_SOIL. The shape was a cuboid (200 millimeter  $\times$  50 millimeter $\times$ 30 millimeter).

TABLE 2 MATERIAL PARAMETERS OF SOIL

Parameter	Value	Parameter	Value
Soil density/( $\text{kg}\cdot\text{m}^{-3}$ )	2850	Cohesive force/MPa	0.1
Poisson's ratio	0.3	Shear modulus/MPa	0.77
Elastic modulus/MPa	20	Bulk modulus/MPa	16.7

#### The Assumption and Mesh of the Whole Model

After the definition of each model's parameters, the positional relation among the models should be estimated. There were three pieces of assumption to make the analysis more accurate. The tool is straight and parallel the ground at the first step of the simulation. In this instant, the cutting tool was straight with the centrifugal force. Secondly, before touching the ground, cutting tool had the same rotation velocity(3000r/min). Thirdly, the cutterhead and cutting tool had the same rotation axis. The distance between rotation axis and the ground was constant. The ground was flat, the hollow and ridge in the field was ignored.

Base on those assumption, the whole model was manufactured as Fig. 3 shown. The cutterhead was free mesh and its holes were minished. The model of cutting tool and the ground were meshed by swept mesh generation.

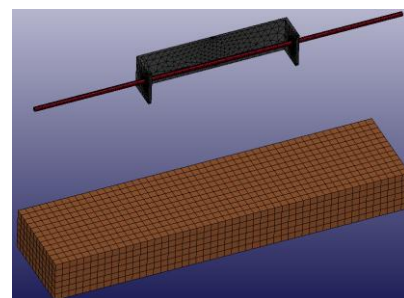


FIG. 3 MODEL AND MESH

The cutterhead and cutting tool were constrained except the Z axis rotation. Non-reflection boundary condition was defined in the model of the ground, for simulating infinite ground. The mesh numbers of cutterhead, cutting tool and ground were 4106, 2400 and 3600 respectively.

### Loading and Contact

In the whole model, there were two sets of contact, cutterhead and cutting tool, ground and cutting tool. Both of them were defined as surface to surface contact (ERODING\_SURFACE\_TO\_SURFACE). The surface of cutting tool was defined as Target surface, then cutterhead and the ground were defined as Contact surface. The cutting tool was driven by the cutterhead, so the cutterhead had constant rotation velocity. Moreover, both cutterhead and cutting tool had the same initial velocity as Table 3 shown.

TABLE 3 LOADING VELOCITY

Model	Initial Palstance	Palstance
Cutterhead	314rad/s(3000r/min)	314rad/s(3000r/min)
Cutting tool	314rad/s(3000r/min)	0

### The Process and Result of Simulation

The target of this simulation was acquiring the load spectrum of the stress. The simulation time was 20 microseconds that cutterhead could take a turn as Fig. 4 shown. Cutting tool was driven by cutterhead, and the bottom of it firstly touching the ground was at 3.5 microsecond. Then the tool was dragged on the ground, which suffered large deformation. The stress and deformation were bigger than which caused by the rotating. Before the tool left the ground, it had the maximum stress at 7.5 microsecond. The tool became straight under the centrifugal force at 9.5 microsecond. Another side of tool repeated this process. At 20 microsecond the simulation was terminated.

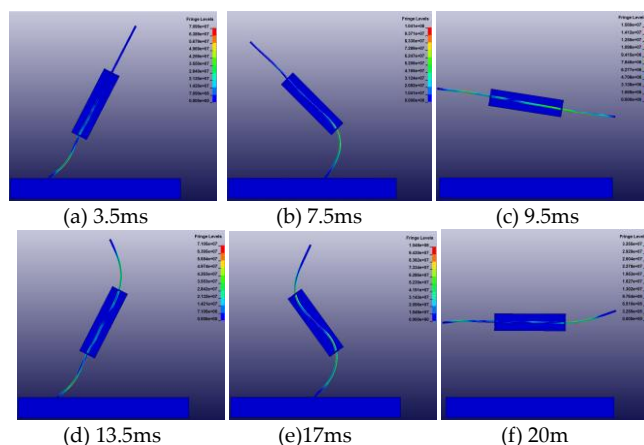


FIG.4 THE PROCESS OF SIMULATION

The stress concentration of cutting tool was segment which was the contact between cutterhead and tool. Because this part had the largest deformation, the tool had the biggest extrusion. The maximum stress of process was 104MPa. Then the VPG software load the result filed of LS-DYNA (d3plot) as the the fatigue load spectrum of the stress.

### Fatigue Simulation of Flexible Cutting Tool

#### Fundamental Principle of Fatigue Simulation

Fatigue analysis in this VPG software was based on the assumption that the most damage areas were experiencing uniaxial stress. Even though that the forces applied to a structure were very complex, stresses in the most critical areas were mainly uniaxial stress.

Von Mises stress at each time step was calculated from ANSYS/LS-DYNA above, which was available from the analysis. The elements stress history was then separated into individual cycles by means of rainflow cycle counting technique and the stress amplitude and the corresponding peak and valley stresses were then used to calculate element fatigue life.

The algorithm VPG used in fatigue life prediction was the Smith-Watson-Topper equation(Wang Yanwei, 2008), which considered the effect of mean stress. Since the assumption was made about the uniaxial stress, the fatigue life calculated would be in the conservative side.

$$\sigma_{\max} \varepsilon_{\alpha} = \frac{\sigma_f}{E} (2N_f)^{2b} + \varepsilon_f \sigma_f (2N_f)^{b+c} \quad (1)$$

where  $\sigma_{\max}$  : maximum stress,  $\varepsilon_{\alpha}$  : amplitude of strain,  $b$  : fatigue strength exponent,  $c$  : fatigue ductility exponent,  $\varepsilon_f$  : fatigue ductility coefficient,  $\sigma_f$  : fatigue ductility coefficient,  $2N_f$  : reversals to failure.

#### The Result of Fatigue of Simulation

For fatigue calculation, VPG firstly opened a new database and set the unit (M, KG, SEC, N). Next, VPG needed to import the model results as he the fatigue load spectrum. Then VPG needed to have specific material properties (PA66) defined for the components in the model, to interpret the stress results for fatigue analysis. After the software finishing the calculation, the result would be shown. Setting the display options, fatigue result contour was shown in Fig. 5. The most dangerous element could recycle ten million times. The short fatigue life of cutting tool was segment which was the contact between cutterhead and tool. It

was parallel to the result of stress. Maybe the cutting tool had large-deformation and high-frequency in these parts. As cutterhead rotated at high speed, the dangerous parts of tool were continuously pressured and stretched. So these parts were easy to fracture.

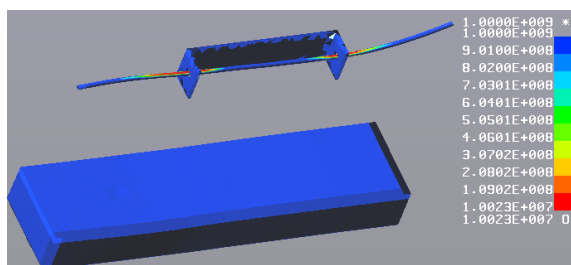


FIG. 5 FATIGUE RESULT CONTOUR PLOT

## Conclusions

This paper simplified the model of cutterhead and cutting tool reasonably. Then ANSYS/LS-DYNA software simulated the process of the flexible large-deformation tool whipping the ground. Next, the fatigue analysis was simulated by VPG software. The paper drew three conclusions from them.

Firstly, there was a new research method to analyse the fatigue life of nonlinear stress recycling nonmetal.

Secondly, the maximum stress appeared in the process of the tool being dragged on the ground. The number of it was 104 MPa, which was much bigger than the maximum of the ground, 0.03MPa. The determinate factor of fatigue was deformation, not the contourforce from the ground.

Thirdly, the short fatigue life of cutting tool was segment which was the contact between cutterhead and tool. It was the way that the tool had frequent and large deformations. The most dangerous element could recycle ten million times.

## ACKNOWLEDGMENT

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